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A tunable and single-frequency S-band erbium fiber laser with saturable-absorber-based autotracking filter

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Abstract

A method to achieve wavelength tunability and single-longitudinal-mode oscillation in an S-band erbium-doped fiber (EDF) ring laser is proposed and demonstrated. A saturable-absorber-based autotracking filter consisting of an unpumped EDF and an optical reflector is utilized to provide fine mode restriction and guarantee the single-frequency operation. The performance of output power of larger than 1 dBm, power stability of smaller than 0.02 dB, wavelength variation of less than 0.01 nm and side-mode suppression ratio of larger than 31 dB has been experimentally demonstrated for this single-frequency fiber laser operating from 1482 to 1512 nm.

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Keywords: Single-frequency; S-band; Fiber ring laser

1. Introduction

Single-longitudinal-mode (SLM) operation for erbium-doped fiber (EDF) ring lasers is becoming all the more necessary. Several techniques have been studied, such as using a passive multiple-ring cavity or a compound ring resonator composed of a dual-coupler fiber ring (DCFR) to guarantee SLM laser oscillation [1,2], integrating two cascaded FFP filters of wide different free spectral ranges (FSRs) into cavity to provide full tunability and SLM operation [3], and using an unpumped

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EDF as a narrow bandwidth autotracking filter [4]. Recently, a fiber ring laser, which can operate at the wavelength range from 1480 to 1520 nm, has been reported [5]. However, this ring laser can not provide SLM oscillation to meet the requirement for a stable S-band light source in future networks. Therefore, in this paper, we propose and experimentally demonstrate a tunable and single-frequency S-band fiber ring laser by using a saturable-absorber-based autotracking filter, which is composed of an unpumped EDF and an optical reflector (OR). The behaviors of the output power and wavelength stabilities, tuning range, side-mode suppression ratio (SMSR), and linewidth spectrum have also been studied.

2. Experimental setup

The experimental setup of the proposed S-band EDF ring laser for single-frequency and wavelength tuning operation is illustrated in Fig. 1. This apparatus comprises a S-band EDFA module, a 90:10 optical coupler, a fiber Fabry–Perot filter (FFP-TP), an optical circulator, a polarization controller (PC), *an unpumped C-band EDF (model DF 1500F of Fibercore Ltd.)*, and an OR. The S-band EDFA module has two amplifier stages and a 980 nm dual-pumping laser source. EDF inside the S-band EDFA module has a depressed cladding design to provide a sharp, high attenuation, long wavelength cutoff filter effect. Besides, the first stage in S-band EDFA module has 20 m EDF and a forward pump in order to obtain low noise figure and high gain. The second stage has the EDF length of 30 m, and large output power through a backward pumping. As a result, a high gain of 32 dB and low noise figure of 5.7 dB performance at 1500 nm can be obtained for small signal power of −25 dBm. The total pump power of this S-band amplifier can be up to 280 mW while the bias current is operated at 356 mA.

SLM oscillation can be realized by employing a FFP-TP filter and a saturable-absorber-based autotracking filter. The FFP filter, which determines operating wavelength of this proposed fiber laser, is an all-fiber device with free spectral range (FSR) of 44.5 nm, finesse of 200, and low insertion loss of <0.5 dB. The filtering wavelength can be tuned by applying voltage on the piezoelectric transducer (PZT) in FFP filter. The saturable-absorber-based autotracking filter consists of an

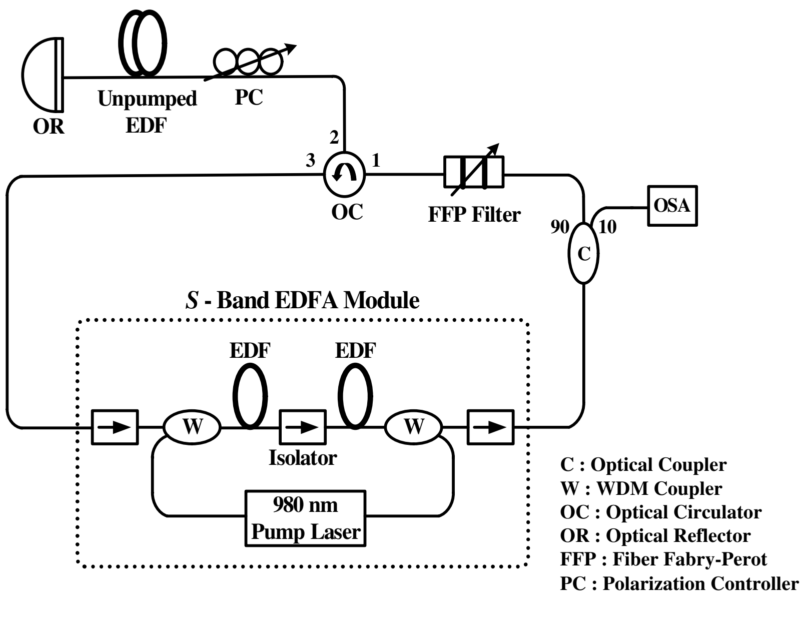

Fig. 1. Experimental setup for the proposed single-frequency S-band EDF ring laser.

unpumped EDF and an OR. The unpumped EDF, with maximum absorption coefficient of 6.3 dB/m at 1531 nm, serves as a saturable absorber. The OR, with nearly 100% reflectivity, can reflect counterpropagating light waves to interfere spatially with propagating light in the saturable absorber. As a result, the spatial hole burning (SHB) effect [4] can be observed in this reflection-typed saturable absorber unit, and a narrow-band Bragg grating filter is, thus, created. By using this saturable-absorber-based autotracking filter and FFP filter, this proposed fiber laser can provide wavelength tunable and single-frequency operation.

In addition, optical spectrum analyzer (OSA) with 0.05 nm resolution is used to measure the output wavelengths and powers of the proposed fiber laser. Furthermore, single-frequency performance is verified by using the delayed self-homodyne method. The optical circuit for measurement is composed of a photodetector with 3 dB bandwidth of 12 GHz and a Mach-Zehnder interferometer with 25 km standard single-mode fiber. The linewidth spectrum of the fiber laser can be measured at photodetector by a radio frequency (RF) spectrum analyzer.

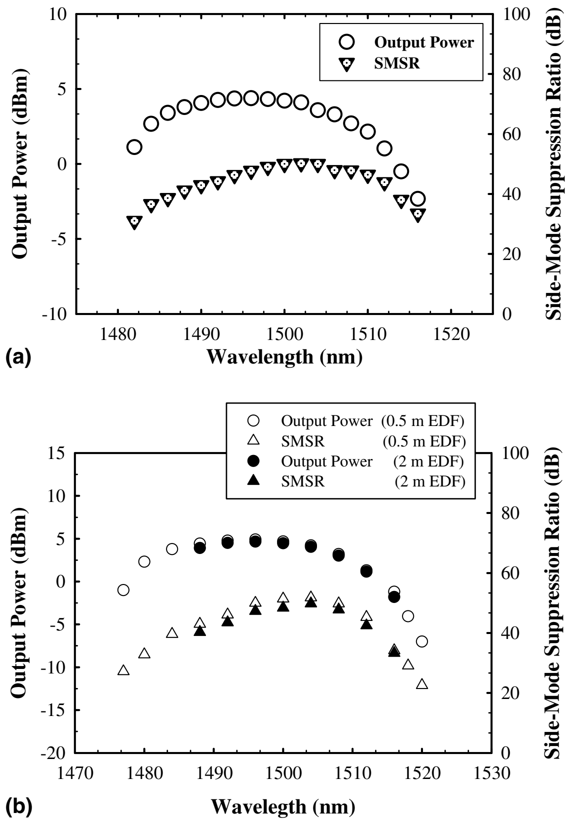

Fig. 2. The output power and SMSR of the proposed fiber laser versus tuning wavelengths with (a) 1 m, (b) 0.5 and 2 m unpumped EDF, respectively.

3. Results and discussions

Fig. 2(a) shows the output power and SMSR of this proposed fiber laser with 1 m unpumped EDF at optical wavelengths ranging from 1482 to 1516 nm. As indicated in Fig. 2(a), the maximal output power of 4.38 dBm is retrieved at around 1496 nm, and the output power is reduced to −2.33 dBm while operating at 1516 nm. For lasing wavelength from 1482 to 1512 nm, output power can keep larger than 1.0 dBm and SMSR can be maintained larger than 31 dB. The output power and SMSR over S-band wavelength range might be flattened if the bias current of the EDFA module is properly adjusted. To choose proper length of unpumped EDF, 0.5 and 2 m EDF as the saturable absorbers are investigated, respectively. As shown in Fig. 2(b), the tuning ranges for 0.5 and 2 m EDF as the saturable absorbers are 1477–1520 and 1488–1516 nm. The results reveal that the wider wavelength tuning range can be achieved by using the shorter length of unpumped EDF. In addition, from linewidth measurement, the single-frequency operation can only be ensured in both 1 and 2 m unpumped EDF cases. Therefore, 1 m is a proper length of unpumped EDF for this experimental setup. From above observation, we know that operating wavelength range and single-frequency oscillation are governed by the length of umpumped EDF. The possible explanation why the umpumped EDF length will determine wavelength tuning range can be described as follows. The ASE spectrum of S-band EDFA module and the absorption spectrum of EDF are shown in Fig. 3. The optical signal will experience around 6 dB loss after a round trip of 1 m unpumped EDF for the wavelength range from 1482 to 1516 nm. As the length of EDF increases, the

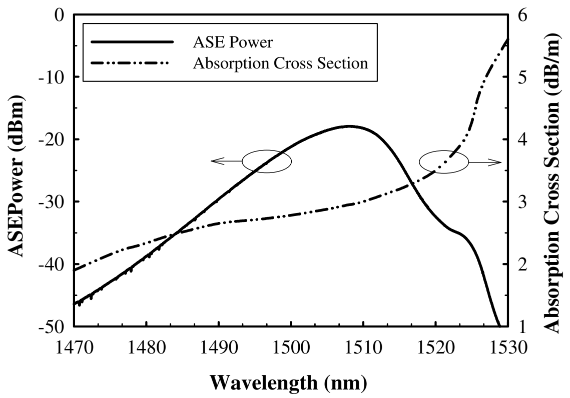

Fig. 3. The ASE spectrum of S-band EDFA module and the absorption spectrum of EDF.

lasing threshold grows and leads to a narrower tuning range due to the increasing cavity loss. On the contrary, in short-length case, tuning range can be obviously extended. However, SLM oscillation in short-length case might not be accomplished because of the broadened bandwidth of the induced autotracking filter.

To verify the single-frequency performance, the linewidth spectrum of this proposed fiber laser is observed by using the delayed self-homodyne technique. Fig. 4 shows the self-homodyne spectra of

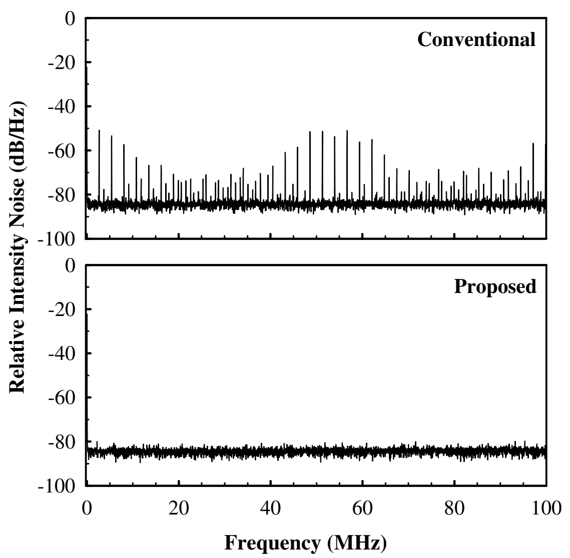

Fig. 4. The self-homodyne spectra of the proposed and conventional ring lasers operated at 1506 nm.

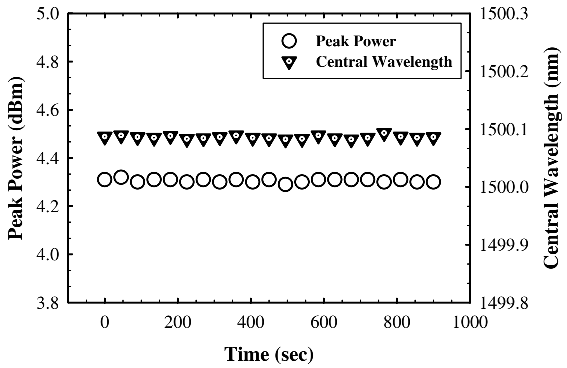

Fig. 5. The output power fluctuation and the wavelength variation of proposed single-frequency fiber ring laser while the wavelength setting at 1500.87 nm initially.

the fiber laser with conventional structure [5] (no saturable absorber) and the proposed fiber laser with 1 m unpumped EDF at 1506 nm. A noisy and unstable waveform with 3.3-MHz mode spacing spikes is observed in the spectrum of the conventional S-band EDF ring laser. Contrarily, no spike signals are observed in the RF spectrum of the proposed fiber laser. Furthermore, output power and wavelength stabilities of the proposed fiber laser with 1 m unpumped EDF are also measured. As indicated in Fig. 5, the initial lasing wavelength is set at 1500.87 nm and the total observing time is over 900 s. Experimental results show that the proposed fiber laser has excellent stabilities. The output power fluctuation is less than 0.02 dB and the central wavelength variation is less than 0.01 nm.

4. Conclusion

We have presented a tunable and single-frequency S-band EDF ring laser with a saturable-absorber-based autotracking filter. By incorporating the saturable-absorber-based autotracking filter with a proper length of unpumped EDF into the ring laser cavity, single-longitudinal-mode oscillation is guaranteed. The output power of larger than 1 dBm and the SMSR of larger than 31 dB over the operation range from 1482 to 1512 nm can be retrieved. Moreover, the power fluctuation of less than 0.02 dB and the central wavelength variation of less than 0.01 nm are also observed. The proposed single-frequency S-band fiber laser is very suitable to future applications.

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